HEAT TREATMENT
OF HIGH SPEED STEEL

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ARMOUR INSTITUTE OF TECHNOLOGY

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Heat treatment of high speed
steels

A THESIS

presented by

PHILIP. F. MILLER

and

HYMEN BORNSTEIN

to the

PRESIDENT AND FACULTY

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HAVING COMPLETED THE PRESCRIBED COURSE IN

CHEMICAL ENGINEERING.

May 25, 1911.

Approved by

Harry McCormack
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HEAT TREATMENT
of
HIGH SPEED STEELS.

By Philip F. Miller
and
Hymen Bornstein.

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Statement:

The object of this investigation was to determine the proper heat treatment for various steels and the best quenching temperature for each.

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I. CHEMICAL ANALYSIS.

In working with the analysis of the steels, it was found that there were really no very rapid methods which could be used. The methods which were finally decided upon gave good results and were quite satisfactory in regard to speed.

1. Sampling.

The steels which were used were very hard and could not be drilled with an ordinary drill. The first step taken in the preparation of samples was to anneal the steel. Some of the steels were already annealed, so that this step was unnecessary. The annealing was done in a muffle furnace. The steel was kept for one hour at a temperature of 720°C. and was allowed to cool in the furnace.

The drilling was done with a high speed twist drill. It was difficult to drill the steels even with this, and it was necessary to regrind the drill at very frequent intervals. Turpentine was tried as a lubricant, but its use is not recommended. It aided somewhat in the drilling but the trouble encountered in getting rid of it far outbalanced the saving of time in drilling.

2. Methods of Analysis.

Carbon.

A solution of copper potassium chloride is made by dissolving 400 grams of the salt in a liter of water and adding five per cent. of hydrochloric acid. After standing a day the solution is filtered.

A three gram sample of the steel is put into a 400c.c.

beaker and 150 c.c. of copper potassium chloride solution added. Acidify with 10 c.c. concentrated hydrochloric acid, heat to 60°C. and stir until the precipitated copper is all dissolved. Filter thru asbestos, but since this steel probably contains chromium it is not advisable to wash with hydrochloric acid. The cake is dried at 110°C. and placed carbon down in the Shimer crucible. The combustion is then run and the carbon dioxide absorbed in a Geissler KOH bulb. The increase in the weight of the bulb gives the weight of CO_2 and from this the per cent. carbon in the steel may be calculated.

Phosphorus.

Dissolve two grams of steel in a 500 c.c. Erlenmeyer flask in 75 c.c. nitric acid (specific gravity 1.13) and add 15 c.c. potassium permanganate solution (5 grams per liter) to the boiling solution. Boil until the pink color disappears. If brown manganese dioxide separates out, the oxidation is complete; if not, add small amounts of the permanganate solution until the MnO_2 separates out. Remove from the heat and add sulphurous acid in small quantities until the solution clears. Allow to cool for a few minutes and then add 13 c.c. ammonium hydroxide (specific gravity 0.90) poring carefully down the sides. Agitate until the ferric hydrate dissolves and cool or heat to 85°C. Add 50 c.c. of ammonium molybdate solution, cork, wrap the flask in a towel, and shake for five minutes. Filter immediately and wash with 1% potassium nitrate solution until the washings are free from acid. Place filter and contents in the flask and add 10 to 20 c.c. of standard sodium hydroxide solu-

tion, accurately measured, and shake to dissolve the precipitate. Add three drops of phenolphtalein solution for an indicator and titrate back just to neutrality with standard nitric acid solution. The solutions of sodium hydroxide and nitric acid should be of about equivalent strength and of such value that one c.c. of alkali is equivalent to .0004 grams phosphorus. From the amount of alkali used the percentage of phosphorus in the steel may be calculated.

Sulphur.

Two grams of the drillings are put in a 500 c.c. flask which is provided with a dropping funnel and a delivery tube. The delivery tube is passed into a Fresenius bulb containing a solution of sodium hydroxide of specific gravity 1.20. The connections must be air tight. One hundred c.c. of 1.10 specific gravity hydrochloric acid are then placed in the dropping funnel and slowly added to the drillings in the flask. After the acid has all been added, the flask is gently heated, the contents being finally brought to boiling to completely expel the hydrogen sulphide which has been formed. The delivery tube is then disconnected from the generating flask, the contents of the bulb washed out into an Erlenmeyer flask, the delivery tube thoroughly washed with distilled water and the washings added to the contents of the beaker. The volume should be made up to 200 c.c. and sufficient hydrchloric acid added to make the solution acid. The solution should at once be titrated against a standard iodine solution. It is best to standardize the iodine solution against a solution obtained by treating a standard pig

iron or steel , in which the sulphur has been determined by the United States Bureau of Standards.

Tungsten.

The contents of the evolution flask from the sulphur determination, which contains the steel in solution, are transferred to an evaporating dish. 25c.c. of concentrated nitric acid are added and the solution is evaporated to a syrupy consistency on the sand bath. 50 c.c. of nitric acid are then added and the solution taken down to dryness on the sand bath. 50 c.c. of concentrated nitric acid are then added and the mass again taken to dryness. Now, one of two things may be done. The dried and baked mass may be ignited. If this is done, the chromium will remain insoluble and stay with the silica portion when treated with acids. If the mass is not ignited the chromium will be soluble in acids and go along with the manganese portion. The difference in treatment will be brought out under the methods for the determination of chromium.

The contents of the evaporating dish or casserole, ignited or not, are treated with 50 c.c. concentrated hydrochloric acid and 50c.c. water. The mass is then boiled and filtered. All the silica and tungstic acid will remain on the filter, as will also a trace of iron oxide. Also, if the mass had been ignited, the chromium will remain on the filter paper. The filtrate is put aside to be used in the determination of manganese. The contents of the filter paper are washed into a beaker by poking a hole in the bottom of the paper with a stirring rod and washing down the contents with a stream of hot water. A

large excess of ammonium hydroxide is now added to the solution in the beaker and the solution heated to boiling. This dissolves out the tungstic acid. The objection of using this method is that the ammonia also dissolves out some of the silica. However, it is believed that this amount is negligible, for when the silica has been baked several times , as is the case here, it is practically insoluble in ammonia. The solution is then filtered and the silica, iron oxide, and chromium (if the mass had been previously ignited as discussed on the previous page) remain on the filter paper. The tungsten remains in solution and is collected in a beaker. Nitric acid is now added to the solution and the tungsten is precipitated as tungstic acid. This is filtered off and ignited at a red heat, for tungstic oxide tends to volatilize at a high temperature. From the weight of tungstic oxide, WO_3, the percentage of tungsten in the steel may readily be calculated.

Silicon.

The filter paper which contains the residue from the tungsten filtration is put into a platinum crucible and ignited. The crucible and contents are then weighed. Ten c.c. of hydrofluoric acid and one drop of sulphuric acid are now added to the contents of the crucible and then evaporated to dryness, preferably on a ring burner. The crucible is then ignited to white heat, cooled in a dessicator and weighed. The loss in weight gives the amount of silica. If the chromium had been made insoluble, it is present in the crucible as the oxide and the crucible should be set aside and the chromium determined as given in the second method for chromium.

Manganese.

The filtrate from the tungstic acid and silica, which contains the manganese, is evaporated to a small volume and 50 c.c. of concentrated nitric acid added. The solution is again evaporated , more nitric acid added and the solution evaporated to a syrupy consistency. 75 c.c. of concentrated nitric acid are then added and the solution brought to the boiling point. Solid potassium chlor~~ide~~ate is added in small quantities and the boiling continued until the manganese is completely precipitated as manganese dioxide. The chromium, if present, is converted into chromic acid. The solution is filtered on asbestos and the residue is washed with nitric acid. The asbestos cake containing the manganese dioxide is washed into an Erlenmeyer flask and a measured quantity of standard ferrous sulphate added. The manganese dioxide dissolves in the ferrous sulphate solution and the excess of ferrous sulphate is titrated back with a standard solution of potassium permanganate.

Chromium. (First method).

If, during the operations for the determination of tungsten, the chromium had not been ignited (see method for the determination of tungsten) then the chromium remained soluble and went along with the manganese. The filtrate from the manganese dioxide (in the determination of manganese) therefore contains the chromium in the form of chromic acid. A measured quantity of ferrous sulphate is added and the excess of the ferrous sulphate solution is titrated back with a standard solution of potassium permanganate. The reactions are as follows:

$2Cr_2O_3 - 6\ FeO = 3Fe_2O_3 - Cr_2O_3,$

$2KMnO_4 - 10\ FeO = K_2O - 2MnO - 5Fe_2O_3.$

Chromium. (Second method).

If, during the operations for the determination of tungsten the chromium had been ignited, then the chromium was made insoluble and went along with the silica. Into the crucible containing the residue from the silica determination, place about ten grams of sodium carbonate and a little potassium nitrate. Heat till quiet fusion. The contents of the crucible are dissolved in hot water and the solution filtered. The residue, consisting of ferric carbonate, is discarded. The filtrate, which contains the chromium, is acidified with acetic acid. The solution is then heated and a hot solution of barium acetate added. The chromium is precipitated in the form of barium chromate. This is filtered on a weighed Gooch crucible and dried. The increase in weight of the crucible gives the weight of the barium chromate.

Nickel.

Dissolve a two gram sample of the steel in 35 c.c. concentrated hydrochloric acid and 1 c.c. nitric acid and evaporate to 10 c.c. Transfer to a 250 c.c. separating funnel and use as little warm hydrchloric acid (2:1) as possible in rinsing the material into the funnel. Cool and add 40c.c. of pure ether which has been previously agitated with 5 c.c. of hydrochloric acid. Shake vigorously, cooling from time to time. Allow to stand and run off the aqueous solution. Wash the ether by shaking with two portions of 5 c.c. each of hydrochloric acid (specific gravity 1.10). Boil out the ether, precipitate the

iron with ammonia, adding a little bromine water to precipitate the manganese. Evaporate the excess of ammonia, obtaining about 100 c.c. of solution containing 1 c.c. of ammonia. Precipitate the nickel by hydrogen sulphide, filter, wash with hydrogen sulphide water, and weigh as nickel sulphide, Ni_2S, containing 78.55% nickel.

ANALYSIS OF STEELS.

	Blue Chip	Novo	Vulcan	Jessops
Tungsten	16.31%	11.21%	15.62%	12.75%
Manganese	.22	.29	.11	.17
Phosphorus	.013	.006	.008	.014
Chromium	3.85	4.24	2.14	4.15
Sulphur	.023	.049	.018	.012
Carbon	.69	.76	.81	1.07
Silicon	.21	.29	.27	.14

II. HEAT TREATMENT.

1. Apparatus used.

The heat treatment was carried on in Hoskins gas heated muffles and in a Hoskins electric furnace of the carbon plate resistance type. Drawings and photographs of these are shown on the following pages.

A LeChatelier pyrometer was used for all the temperature measurements. This pyrometer was a standardized one, thus insuring accurate measurements.

2. Specimens.

The specimens used were 3/8 inch by 1/2 inch in section and about eight inches long. These were convenient to handle and were easily broken for fracture photographs.

3. Method.

On investigation of past practice it was found that the temperatures used varied from a minimum of 1000°C. to a maximum of 1250°C. Therefore, six different temperatures were decided upon, which were as follows:- 1040°, 1080°, 1120°, 1160°, 1200o, and 1240°C.

The specimens were laid in the furnace side by side and the temperature slowly raised. As each temperature was reached, as indicated by the pyrometer, the specimen was removed and quenched in the air blast.

The air blast for quenching was made from pipe connections and, as can be seen from the sketch, it is merely a piece of one inch pipe connected to a compressed air supply. The specimen was placed in the pipe and the blast turned on.

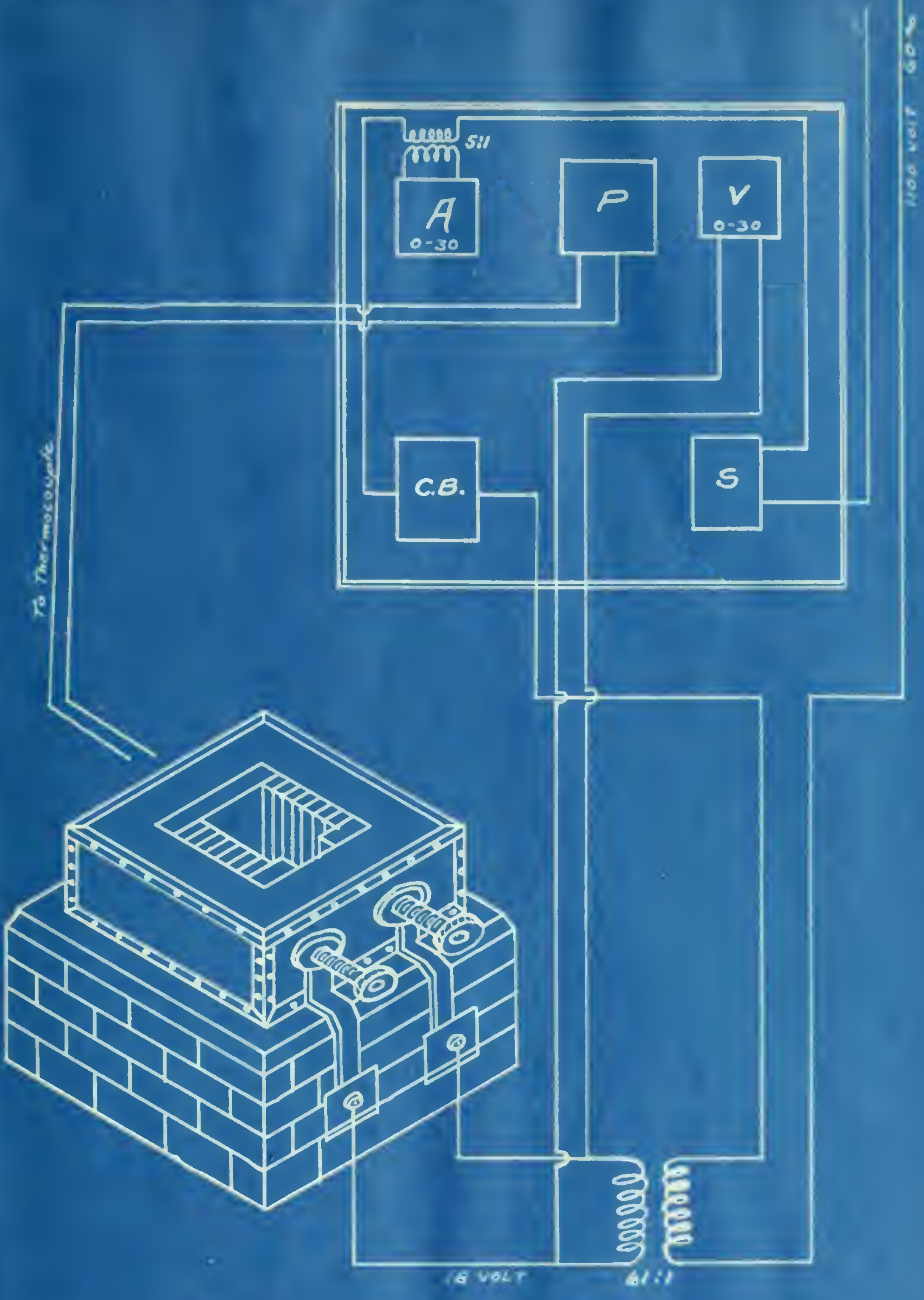
The pipe concentrated the air on the specimen, thus cooling it more rapidly.

4. Discussion.

The specimens subjected to the higher temperatures in the gas muffle seemed to scale over a great deal, owing to the length of time necessary to leave them in the furnace. For this reason, the electric furnace is recommended for high temperature work. Also, the addition of charcoal in the furnace with the steel produced a reducing atmosphere and thereby prevented the scaling of the specimens.

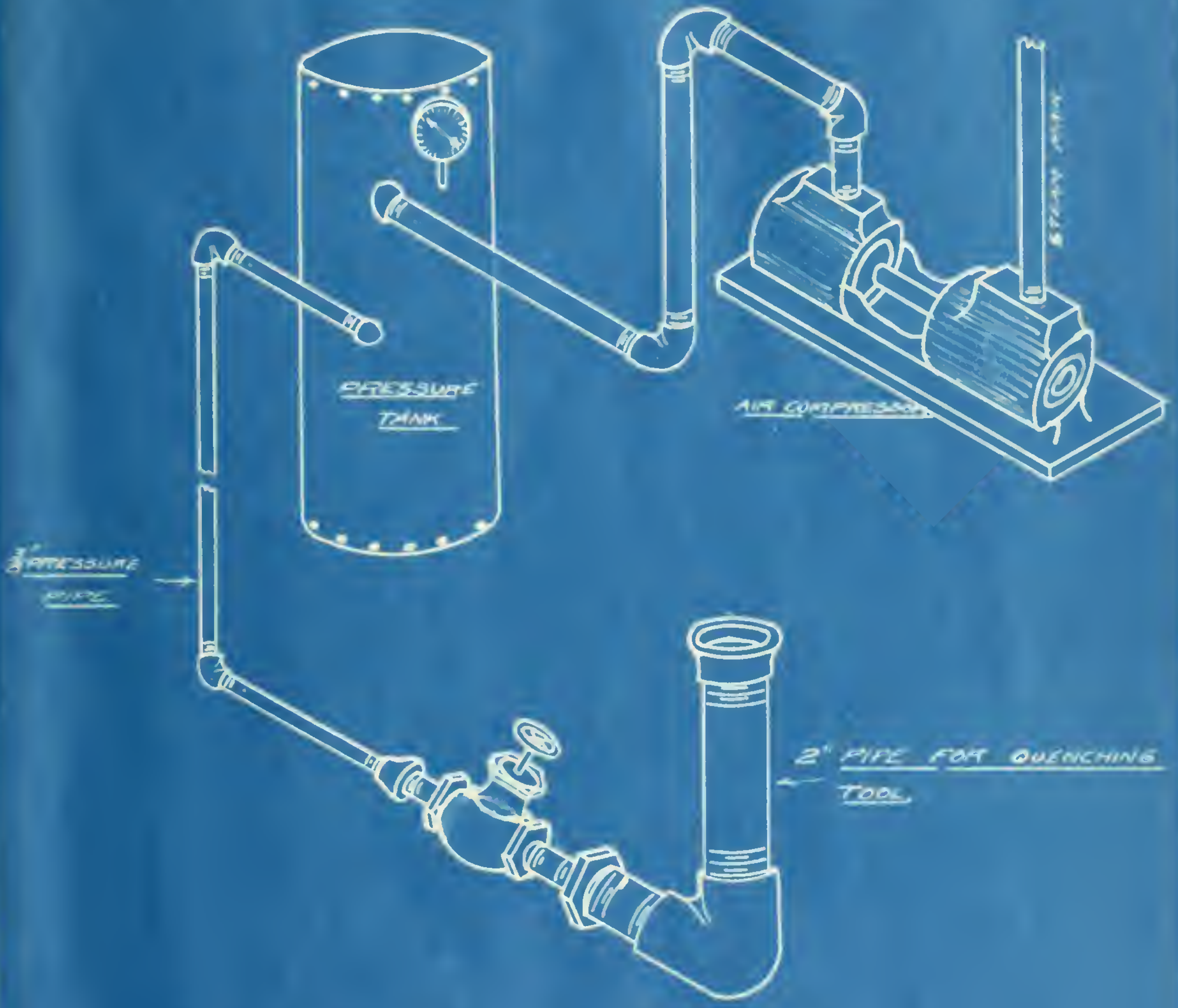
Considerable difficulty was encountered in getting the specimens quickly into the air blast after removal from the furnace. This was lessened by raising the temperature slightly above the desired temperature before removal.

The ease with which the specimens were broken seemed to increase directly with the temperature at which they were quenched. That is, the annealed steel is the most difficult to fracture while the specimen subjected to the highest temperature fractures most easily. However, this was partly due to the reduced sectional area of the specimens heated to a high temperature. The reduced section was caused by the oxidation of the steel.



ELECTRIC FURNACE AND SWITCHBOARD.

P.F. Miller



AIR BLAST APPARATUS
FOR QUENCHING.

R.F. Miller 4-9-11.

III. PHOTOGRAPHIC EXAMINATION.

A. Photographs of fractures.

1. Apparatus.

For the work on fracture photographs the apparatus consisted simply in a camera and the ordinary dark room arrangements.

The camera was made by using the bellows from a photo-micrograph camera, laid sidewise and placing on one end a short focus, single lens. The specimen was placed about five inches in front of the lens. The illumination came from the side and care was taken to cast as few shadows as possible. A high candle power incandescent lamp was used and the light was focussed on the specimen by a large lens. The rear of the bellows was fitted with a ground glass and plate holder attachment. A photograph of the apparatus is shown on a following page.

2. Specimen.

The specimens were obtained from the specimens used for the heat treatment. A piece about two inches in length was broken off from the heated end of each specimen.

3. Method.

The test piece was placed in the holder and the light focussed on it. The image was then focussed on the ground glass by adjusting the bellows, and the specimen moved back and forth until the proper size of image was obtained. Care was taken in placing the specimen to get it as parallel to the plane of the lens as possible. This occasioned con-

siderable difficulty, since the pieces broke so irregularly. With the focal distance and illumination used, it was found that an exposure of seventeen seconds gave the best results. The plates were developed in the usual way and prints on Velox paper were made.

4. Discussion.

Considerable difficulty was encountered, first of all, due to the fact that the specimens broke so irregularly. However, the results obtained serve to show the size of the grain and the general structure of the specimen.

In the Blue Chip steel the fracture of the annealed steel resembled that of gray cast iron very closely. As the temperature of quenching was increased, the specimens broke more irregularly up to 1120°C. where the fracture became very smooth and fine grained. It was at first thought that this smoothness or silkiness of fracture indicated the proper quenching temperature; but on testing the tools in the lathe it was found that the tool quenched at 1120°C. broke off, thus indicating extreme brittleness. From 1120° on the grain gradually increased in size, until at 1540° the grains were extremely coarse.

The Vulcan steel differed somewhat from the Blue Chip as none of the fractures showed the fine silky texture which was found in the Blue Chip. All the specimens broke irregularly, the size of the grain increasing with increase of temperature.

The Novo steel acted similarly to the Vulcan, except

that at 1120°C. a fine grained specimen was obtained which did not work well in the lathe.

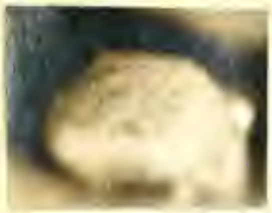
The Jessops steel was peculiar in that all its fractures were quite smooth, thus indicating hardness. Also, in fracturing the steel it seemed very tough. Notwithstanding these qualities, the steel did not work at all well in the lathe.

Considering all the results obtained, they seem to indicate that the best fracture is similar to Blue Chip #3, Novo #3, or Novo #5. The granular fractures seem to indicate brittleness, while those with finely serrated ridges seem to indicate toughness. The smooth or silky fractures show that the steel is extremely brittle and not suitable for work in the lathe.

BLUE CHIP STEEL.

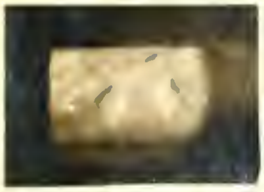
FRACTURES.

1.



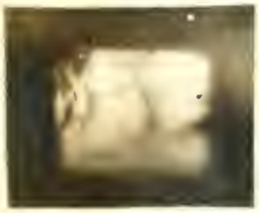
#1. Annealed steel.

2.



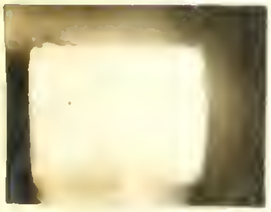
#2. Steel heated to 1040° C. and quenched in air blast.

3.



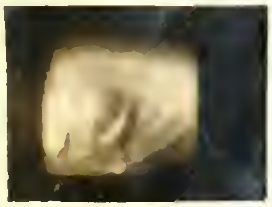
#3. Steel heated to 1080°C. and quenched in air blast.

4.



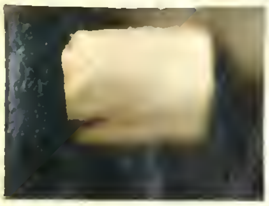
#4. Steel heated to 1120°C. and quenched in air blast.

5.



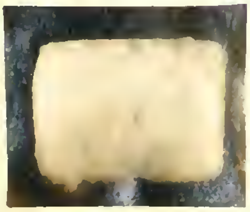
#5. Steel heated to 1160°C. and quenched in air blast.

6.



#6. Steel heated to 1200°C. and quenched in air blast.

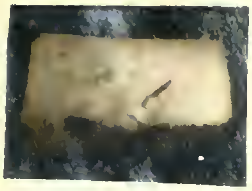
7.



#7. Steel heated to 1240°C. and quenched in air blast.

VULCAN STEEL.

FRACTURES.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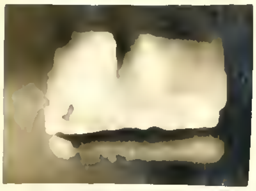
1. Annealed steel.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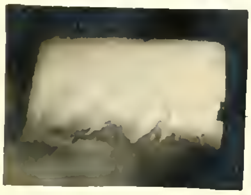
2. Steel heated to 1040°C. and quenched in air blast.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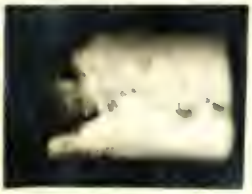
3. Steel heated to 1080°C. and quenched in air blast.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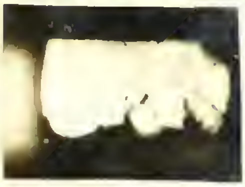
4. Steel heated to 1120°C. and quenched in air blast.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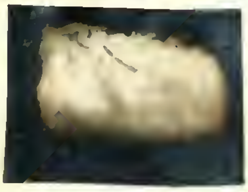
5. Steel heated to 1160°C. and quenched in air blast.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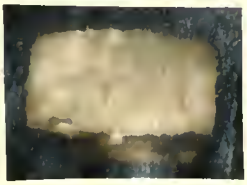
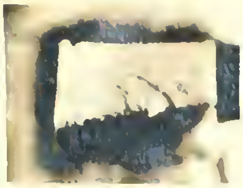
6. Steel heated to 1200°C. and quenched in air blast.


7

7. Steel heated to 1240°C. and quenched in air blast.

NOVO STEEL.

FRACTURES.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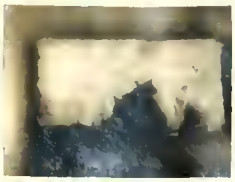
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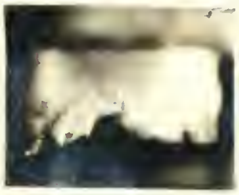
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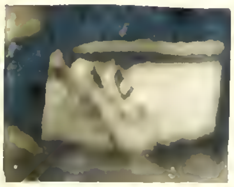
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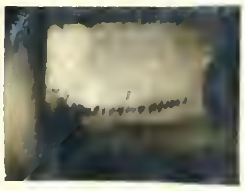
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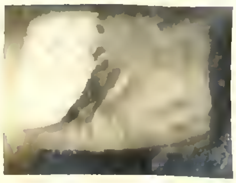

6

1. Annealed steel.

2. Steel heated to 1040°C. and quenched in air.blast.

3. Steel heated to 1080°C. and quenched in air blast.

4. Steel heated to 1120°C. and quenched in air blast.

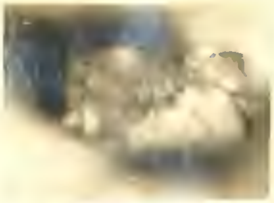
5. Steel heated to 1160°C. and quenched in air blast.

6. Steel heated to 1200°C. and quenched in air blast.

7. Steel heated to 1240°C. and quenched in air blast.

JESSOP'S STEEL.

FRACTURES.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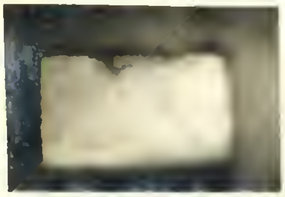
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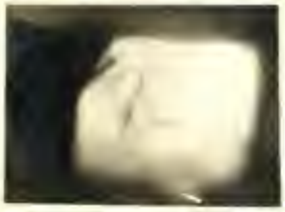
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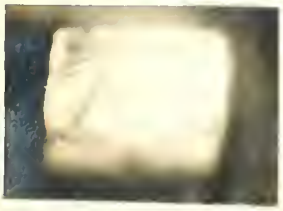
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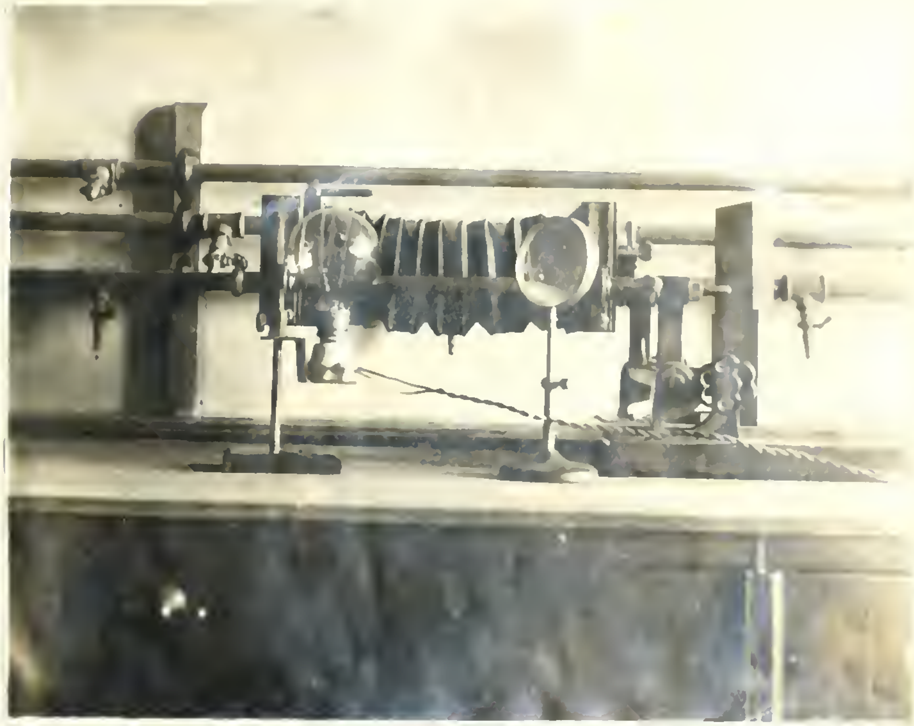
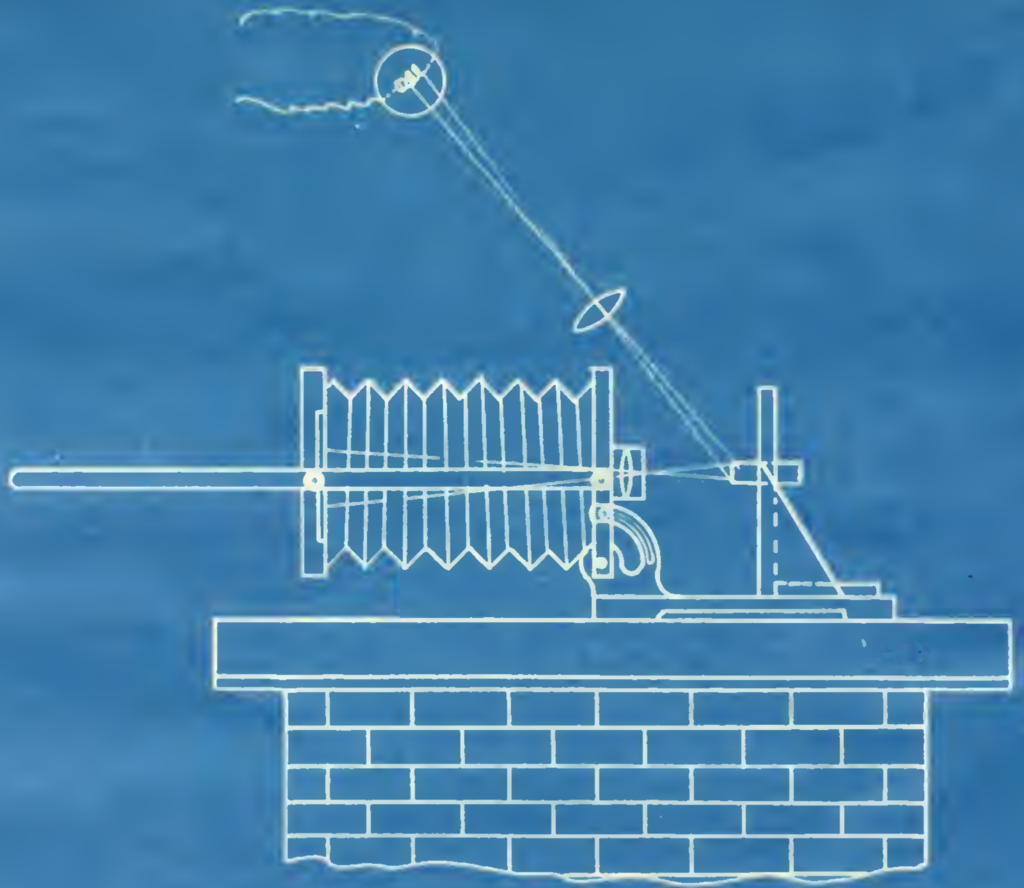
#7. Steel heated to 1240°C. and quenched in air blast.





SCHEME FOR TAKING PHOTOGRAPHS OF FRACTURES

[illegible] 4-5-11

B. Photomicrographs.

1. Apparatus.

The photographic outfit employed was a camera bellows placed over the eye piece of a Bausch & Lomb high power microscope. The light was reflected in from the side by means of a high candle power incandescent lamp and a lens; this light was rectified by means of a light adapter.

The polishing and grinding apparatus consisted of two double surfaced power driven wheels. One of the wheels had a corundum stone surface, its other surface being canvas. The canvas side was coated with emery flour in order to give the grinding surface. The other wheel had broadcloth surfaces and these were coated with tripoli and rouge respectively.

2. Specimens.

The specimens used were the same as those used for the fracture photographs.

3. Method.

The specimens were first ground flat by a coarse grinding wheel. The scratches were almost all removed by grinding on the canvas wheel coated with emery flour. The specimen was then polished on the tripoli wheel and the final polishing was done with the rouge. Considerable care was used in all the grinding and polishing operations in order to secure a flat surface free from scratches. The wheels were wetted constantly during the operations. The rouge wheel polishing was continued until the steel took on a bright, mirror like surface, free from scratches.

It was somewhat difficult to etch the specimens, the reagent used depending upon the hardness of the specimen. A solution of picric acid in alcohol was used for the softer ones, concentrated nitric acid for the medium hard, and dilute nitric acid for the hardest ones. The etching was done slowly and its progress was noted by repeated examinations under the microscope.

The etched specimen was then placed in the specimen holder and the objective brought down onto it. Considerable adjustment was necessary to get it to the plane of the objective. The light was let in from the side, using the same lamp and lens as were used for the fracture camera. The 1/12 inch objective and a 3/4 inch eye piece were used giving a magnification of 900 diameters.

After focussing and obtaining a good field, the camera bellows was dropped over the eye piece and the image focussed on the ground glass. The work was carried out on a brick pier to reduce vibrations as far as possible and the greatest care was taken in obtaining a focus, since the slightest disarrangement or jar would throw it out. After focussing on the ground glass the plate holder was substituted for it and the exposure made. the time of exposure varied from one and one half to four minutes, depending upon the appearance of the field. The negatives were developed in the usual way and Velox prints were made from each one. The prints are shown on a following page.

4. Discussion.

The results obtained were only fair on account of the poor facilities at hand in regard to a firm and steady place for taking the pictures. As a result of this, focussing was difficult and every jar helped to blur the image. However, the form of the structure is shown fairly well and is of some value.

The photomicrographs of the Blue Chip Steel show a similarity up to 1200°C. where the character of the crystals changes rapidly. The first five specimens show coarse crystals at a considerable distance from each other, while the last two specimens are of a blistered appearance. These last, as found later, indicated extreme hardness, though not toughness. It is a peculiar instance that Blue Chip #4, which had the finest grained fracture, had the coarsest crystals.

The Vulcan steel exhibited properties similar to that of Blue Chip, only the crystals were much finer and were present in larger numbers.

In the case of the Novo steel, the structures were all very similar, showing that the structure is little influenced by the temperature. This is probably the reason why the steel ran so well in the lathe at all temperatures of quenching.

All the specimens of the Jessops steel exhibited properties like those of Blue Chip #6 and #7. That is to say, they had a blister like appearance. This indicates extreme hardness, which probably accounts for the poor performance of the Jessops tools.

On the whole, the crystalline structures of all the

steels seemed to indicate that the fine or coarse granular structures were tough and hard while the blister like structures were brittle. The best structure is one like Novo "3 and "5, which are fine crystalline structures.

It is quite well to notice that the results obtained from the photomicrographs agree very well with those from the fracture photographs. For instance, it was found that the specimens that gave a smooth or silky fracture were very hard and brittle and did not work well in the lathe. It was these same specimens and only these that gave the blistered appearance under the microscope.

2.

BLUE CHIP.

5.

3.

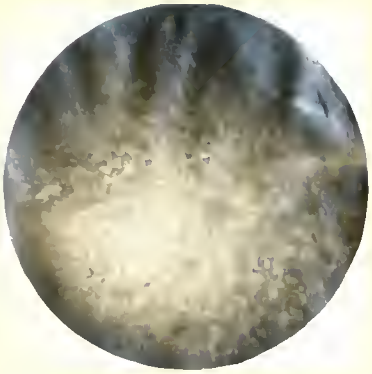
1.

6.

4.

7.

VULCAN.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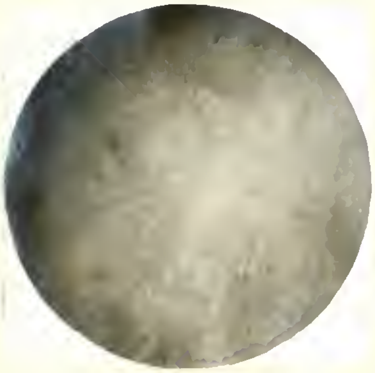
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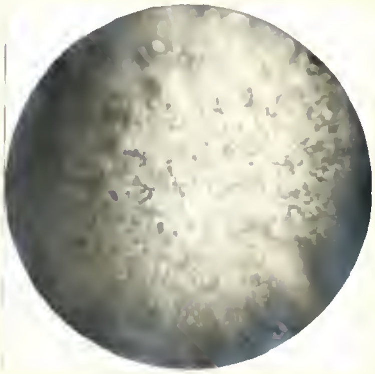
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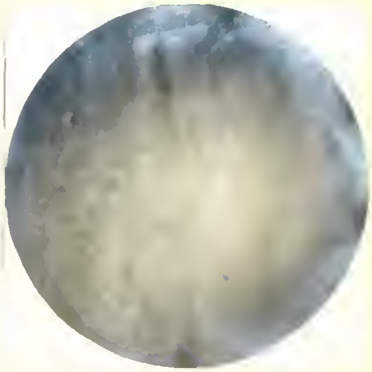
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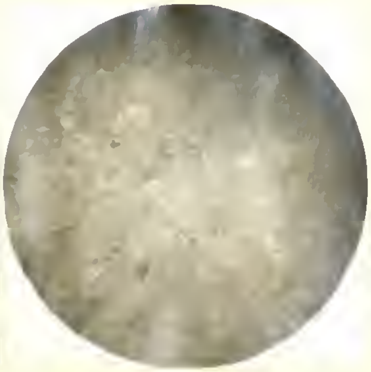
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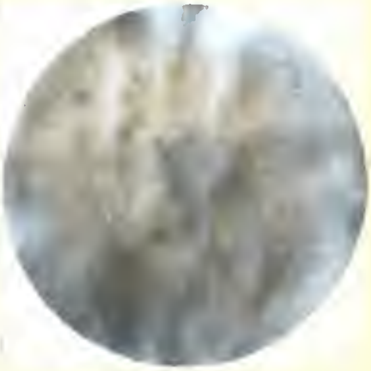
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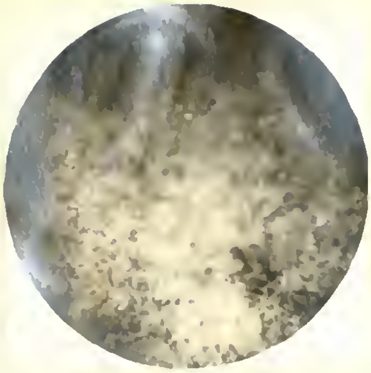
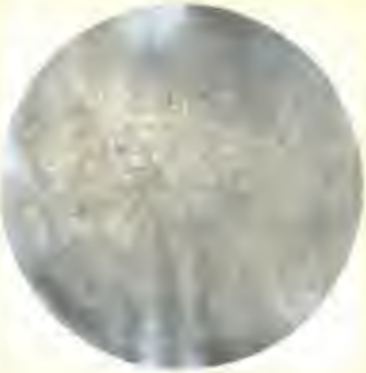


2.

NOVO.



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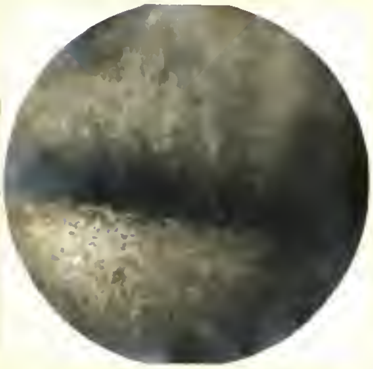

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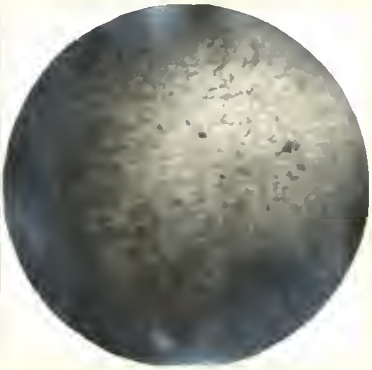

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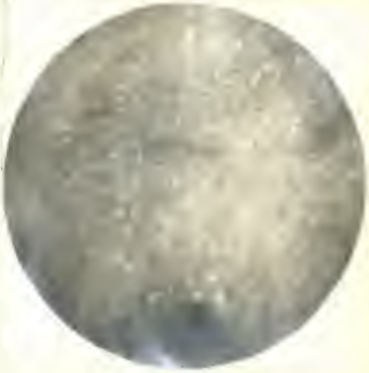

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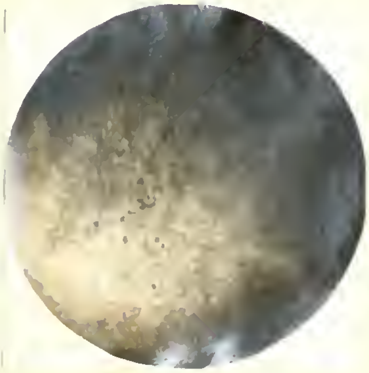

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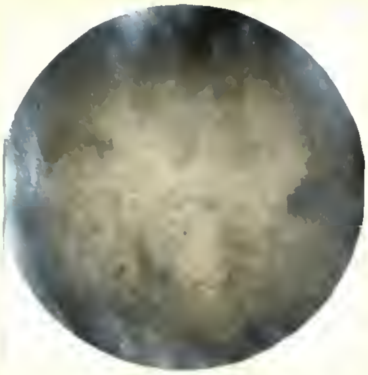


2.

JESSOPS.

4.

3.

1.

5.

P., Pier.

B., Camera Bellows.

G., Ground Glass and Photo Holder.

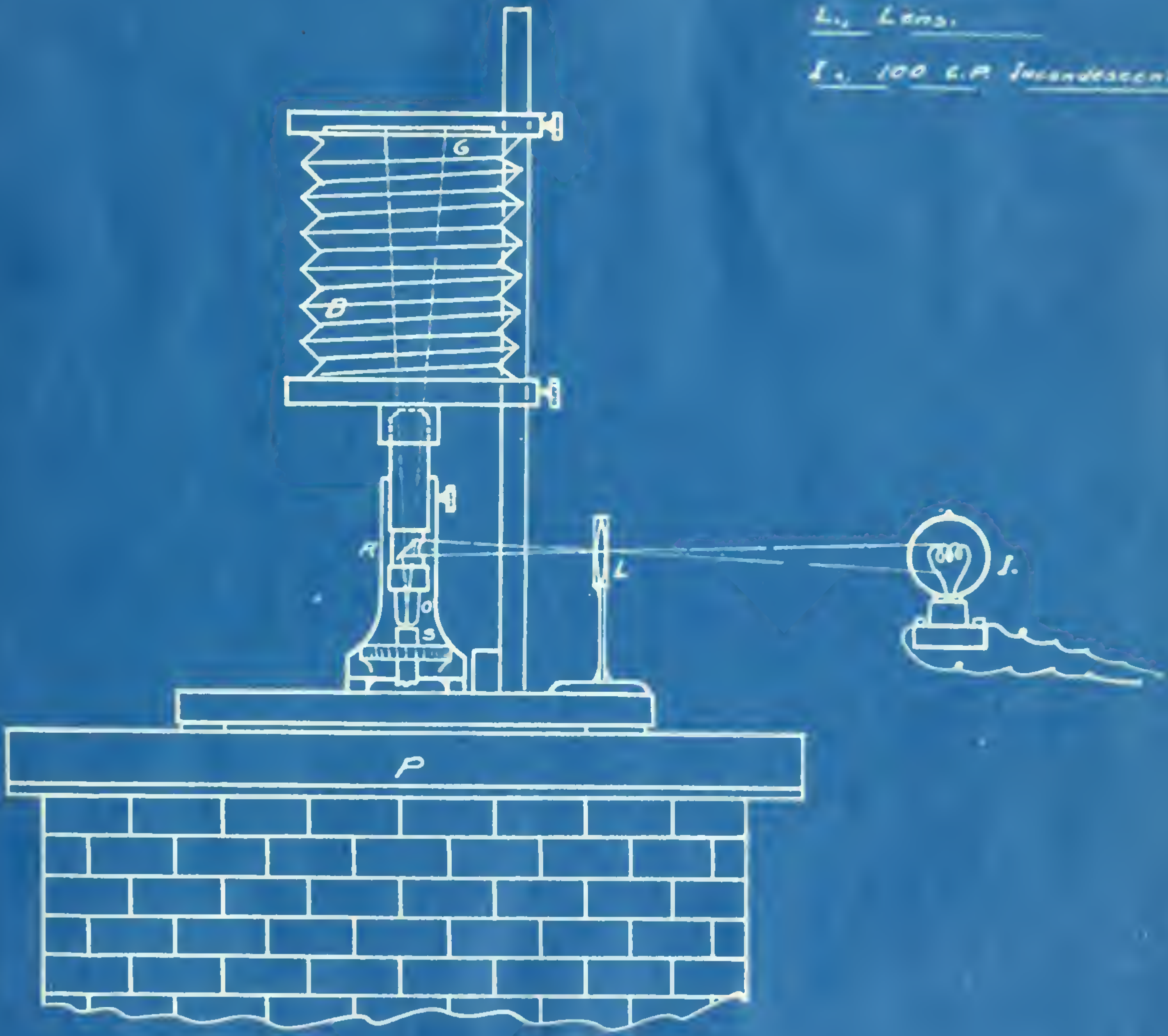
R., Light Adapter.

O., Microscope Objective.

S., Specimen.

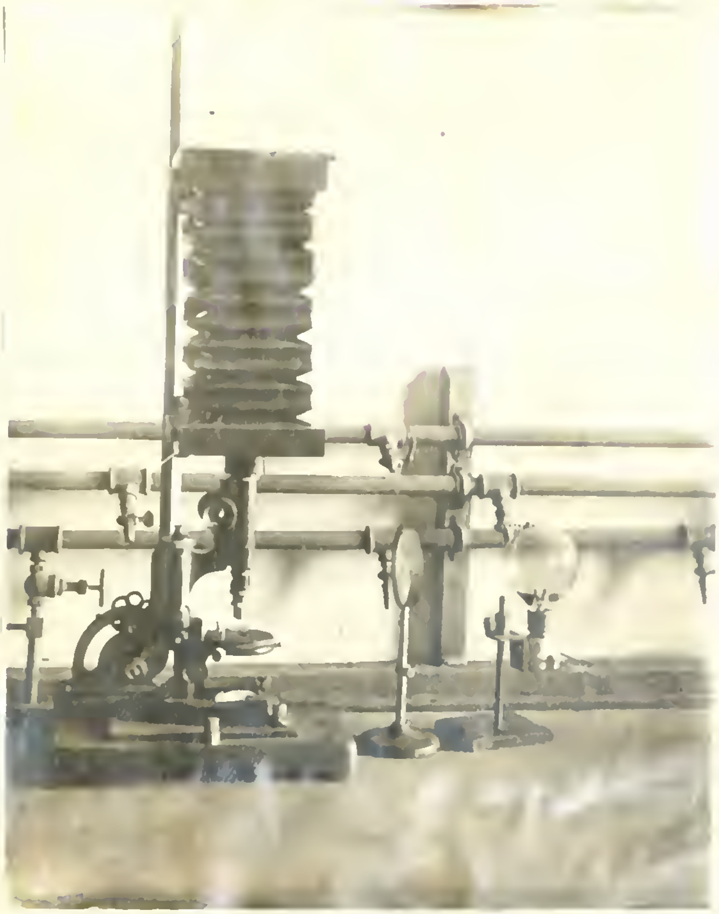
L., Lens.

I., 100 C.P. Incandescent



SCHEME FOR TAKING PHOTOMICHROGRAPHS.

P.F. Miller 4-5-11



IV. SHOP TESTS.

1. Apparatus.

The shop tests were in the nature of determining the cutting powers of the tools subjected to the various temperatures before quenching. All the tests were carried out on a Marshall & Huschart 16 inch motor driven lathe. An ammeter and voltmeter were hooked in to measure the power input.

The gas muffle and electric furnace were used for heating the tools, the same as for the preliminary heat treatment. A Warner cut-meter was used to determine the cutting speed.

2. Specimens.

The tools used were standard 1/2 inch by 1 inch round nose roughing tools as illustrated in the sketch on the following page. The test pieces were cast iron cylinders 30 inches long and 4 inches in diameter. In order to insure these test pieces being the same hardness, they were all cast at the same foundry heat.

3. Method.

The tools were roughly forged and then ground to size and shape exactly alike. A voltmeter and ammeter were placed on the motor to measure the power input and a rheostat was put in the field to control the speed. The test pieces were mounted between centers and a cut taken across to remove the scale.

The tools were all first heated to the first temperature determined, i.e. 1040°C., and quenched in the air blast. They were then ground and tested on the cast iron test pieces

one at a time as follows.

The tool was set for a 5/32 inch cut and a .0051 inch feed and started at the work. The cutting speed was determined by the Warner cut-meter and kept as near 90 feet a minute as possible. The time was taken when the tool started to cut and when it gave way. The point of failure was extremely hard to determine since the ammeter gave little or no indication as to the condition of the tool and the cutting edge was so hidden by chips as to be out of sight all the time. However, by watching the marks of the tool and the ammeter, the point of failure was fairly well determined and on the removal of the tool it was nearly always found to have failed.

The following data was taken for each tool and tabulated;

Voltage on motor.

Current input.

Cutting speed.

Feed.

Depth of cut.

Life of tool.

The tools were heated to all the other determined temperatures and the same operations were gone through for each of the temperatures.

4. Discussion.

Lathe tests of this character are of necessity only approximate. This is true because of the impossibility of keeping conditions uniform and because it was impossible to [illegible]r-

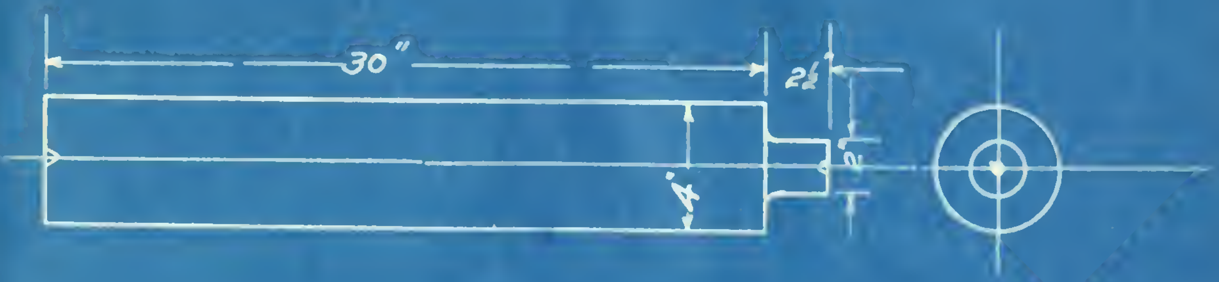
ately judge the point of failure of a tool.

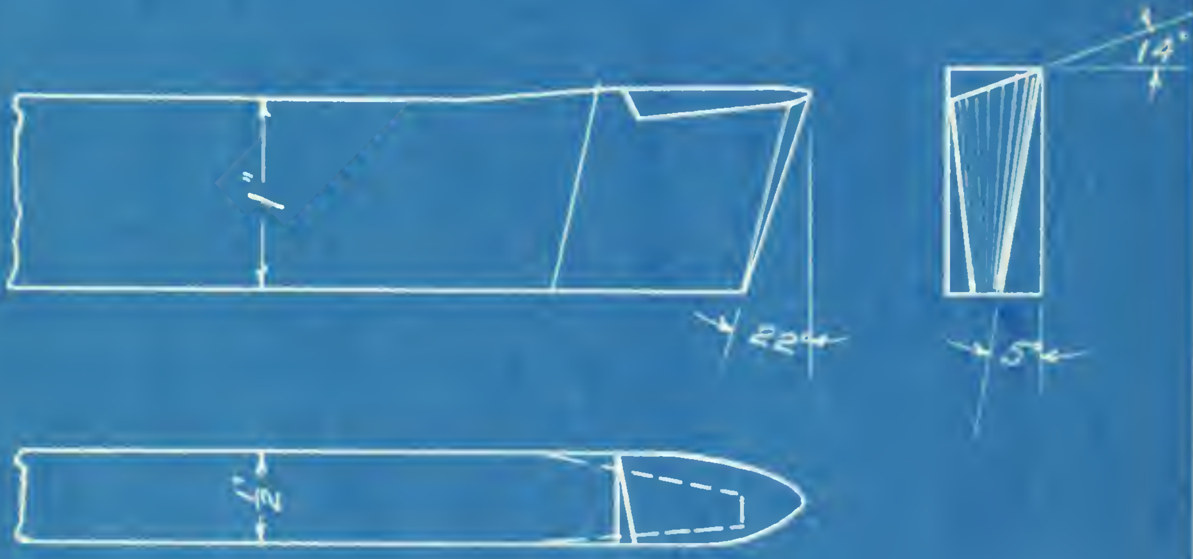
The object of the test was primarily to ascertain the best temperature at which to quench the tools, but it was also desired to compare the relative merits of the different steels. Therefore, conditions were kept as nearly uniform as possible. A cut of 5/32 inch and a feed of .0351 inch were used as well as a cutting speed of 85 to 90 feet per minute. These conditions were much better for the Blue Chip and Novo steels than for the Jessops and Vulcan, so the results on the last two are not of much value. Unquestionably, the best quenching temperature for the Blue Chip steel is about 1080°C. When quenched at this temperature it ran for ten minutes at heavy work without a sign of failure and had to be stopped because it had reached the end of the test piece. Below this temperature it worked fairly well and above this temperature the tool broke.

The Novo steel seemed to work well between the quenching temperatures of 1080° and 1160°C. showing a wider range of working than the Blue Chip. This was indicated by the similarity of the structures at the different temperatures.

The Jessops and Vulcan steels did poor work compared with the others. However, the best temperature for quenching for the Vulcan seemed to be 1040°C. and for the Jessops it was 1200°C.

The lathe tests as a whole seemed to give a fairly good indication of the best temperatures for quenching. This was the result primarily sought for.





TEST PIECE AND FORM OF ROUGHING TOOL USED IN LATHE TESTS.

P.F. Miller 4-8-11

LATHE TEST OF "BLUE CHIP" STEEL.

SPECIMEN	TEMP. °C. HEATED TO	QUENCHED.	VOLTAGE ON MOTOR	LINE CURRENT.	POWER INPUT H.P	CUTTING SPEED-FT/MIN	DEPTH OF CUT	FEED	LIFE - MIN.	KIND OF FAILURE	MATERIAL TESTED ON		
2	1040	AIR	112	17	2.55	92	$\frac{9}{64}$"	.0351"	1.83	BURNT.	C.I.		
3	1080	"	112	18	2.70	86	$\frac{5}{32}$"	.0351"	10.00	"	"		
4	1120	"	BROKE IN HOLDER. TOO HARD.										

LATHE TEST OF "VULCAN" STEEL

SPECIMEN	TEMP. °C HEATED TO	QUENCHED	VOLTAGE ON MOTOR	LINE CURRENT.	POWER INPUT	CUTTING SPEED-FT/MIN	DEPTH OF CUT.	FEED	LIFE - MIN.	KIND OF FAILURE.	MATERIAL TESTED ON.
2	1040	AIR	112	16	2.40	84	$\frac{5}{32}$"	.0351	.66	BURNT.	C.I.
3	1080	"	106	16	2.28	81	$\frac{9}{64}$"	"	3.66	"	"
4	1120	"	110	18	2.65	92	$\frac{5}{32}$"	"	.17	"	"
5	1160	"	110	18	2.65	87	$\frac{5}{32}$"	"	.17	"	"
6	1200	"	110	18	2.65	90	$\frac{5}{32}$"	"	.08	"	"

LATHE TEST OF "NOVO" STEEL.

SPECIMEN	TEMP. °C HEATED TO	QUENCHED	VOLTAGE ON MOTOR	LINE CURRENT	POWER INPUT H.P.	CUTTING SPEED-FT/MIN	DEPTH OF CUT	FEED	LIFE -MIN.	KIND OF FAILURE			
2	1040	AIR	112	15	2.25	88	$\frac{9}{64}$"	.0351	5.00	Burnt			
3	1080	"	112	18	2.70	80	$\frac{5}{32}$"	.0351	2.83	"			
4	1120	"	110	18	2.65	92	$\frac{5}{32}$"	"	.60	"			
5	1160	"	110	20	3.04	87	$\frac{5}{32}$"	"	5.00	"			
6	1200	"	110	18	2.65	88	$\frac{5}{32}$"	"	.66	"			

LATHE TEST OF "JESSOPS" STEEL

SPECIMEN	TEMP °C. HEATED TO	QUENCHED.	VOLTAGE ON MOTOR	LINE CURRENT.	POWER INPUT. H.P.	CUTTING SPEED-FT/MIN	DEPTH OF CUT.	FEED	LIFE - MIN	KIND OF FAILURE.	MATERIAL TESTED ON		
2	1040	AIR.	112	18	2.70	84	$\frac{5}{32}$"	.0351"	.5	BURNT.	C.I.		
3	1080	"	110	22	3.24	92	$\frac{5}{32}$"	"	.75	"	"		
4	1120	"	110	18	2.65	92	$\frac{5}{32}$"	"	.17	"	"		
5	1160	"	110	18	2.65	87	$\frac{5}{32}$"	"	.34	"	"		
6	1200	"	110	18	2.65	90	$\frac{5}{32}$"	"	.50	"	"		